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A DIGITAL IF SIMULATOR FOR FM RANGING SYSTEMS.(U)
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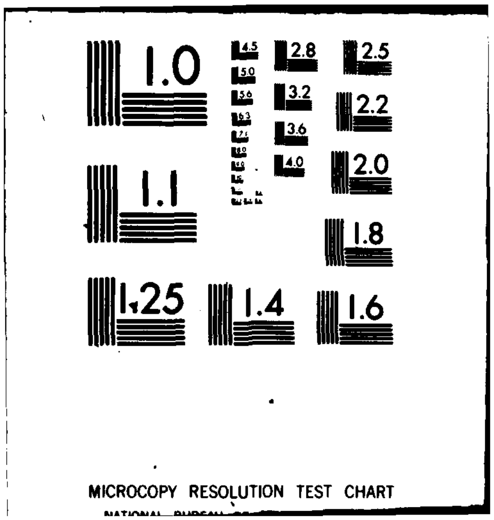
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: HDL-CR-80-074-1	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): A DIGITAL IF SIMULATOR FOR FM RANGING SYSTEMS	5. TYPE OF REPORT & PERIOD COVERED: Contractor Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Marion C. Bartlett, Raymond C. Johnson	8. CONTRACT OR GRANT NUMBER(s): DAAG39-78-C-0074
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Engineering And Industrial Experiment Station, UNIVERSITY OF FLORIDA, Gainesville, FL 32611	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Program element:6.26.16.A, HDL Proj: A77737
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. ARMY MATERIEL DEVELOPMENT & READINESS COMMAND, Alexandria, VA 22333	12. REPORT DATE: March 1980
	13. NUMBER OF PAGES: 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): HARRY DIAMOND LABORATORIES, 2800 Powder Mill Road, Adelphi, MD 20783	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

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APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Work Unit Title: Fuze Technology

DA-1L662616AH77 DRCMS Code: 662616.11.H7700

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FM ranging systems
Signal simulator
Intermediate frequency
Ambiguity
Digital signal processing
PROM
EPROM

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A digital intermediate frequency signal simulator (DIFSS) which is useful for testing many periodically modulated FM ranging systems is described. The DIFSS digitally computes the IF signal angle using angle tables stored in EPROM's and generates the cosine of the angle with a cosine PROM and D/A converter. Target delay time τ and doppler frequency can be varied as desired for static tests or dynamic target trajectories. The simulator is useful for testing real-time hardware or for testing ambiguous ranging system responses in a scaled-time mode.

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1. INTRODUCTION

Signal simulators generating delayed and attenuated signals which approximate target returns are important tools in the development and evaluation of FM ranging systems. The most direct approach to this problem is to delay and attenuate the transmitted RF signal. Variation of delay and attenuation as the relative target position changes then naturally produces a proper test signal complete with doppler effects. In practice, it is many times very difficult to achieve continuous, controllable delays for wideband RF signals; consequently, other methods must be considered. One of the most useful alternatives is to generate the IF signal which results from product mixing the transmitted and returned signals and filtering to remove the output at double the RF carrier frequency. IF signal simulators can be constructed with less difficulty than their RF counterparts and are useful in testing many FM ranging systems.

A previous report[1] described an IF signal simulator (IFSS) technique which was applicable for all modulation waveforms. This simulator was useful for testing most range responses, but was limited to some degree due to the use of an RF delay line for the delay mechanism. In particular, the ambiguous system responses to signals exhibiting long delays and large doppler shifts could not be tested. In addition, the high attenuation associated with long RF delay lines presented some difficulties in testing the range responses of long delay ranging systems.

This report describes a digital IF signal simulator (DIFSS) designed for testing FM ranging systems which use periodic modulations. The DIFSS is in large part a hardware implementation of digital computer models which have been developed at this laboratory for analyzing FM ranging systems. This simulator can be used to generate real-time IF signals for testing hardware and will also generate IF signals for testing ambiguous ranging system responses in scaled-time testing situations.

2. FM RANGING SYSTEM DESCRIPTION

The FM transmitter (fig. 1) is frequency modulated by a voltage m(t) obtained from a modulation generator. The transmitted signal x(t) and the

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[1] M. C. Bartlett and R. C. Johnson, An I.F. Signal Simulator for FM Ranging Systems, Harry Diamond Laboratories, HDL-CR-77-045-1 (June 1977).

attenuated return signal $kx(t - \tau)$ are product mixed and filtered to obtain the IF signal $s(t)$. In this illustration separate transmit and receive antennas are shown; however, systems which employ a common transmit/receive antenna and obtain the IF signal by envelope-detecting the composite antenna voltage are mathematically equivalent to figure 1.

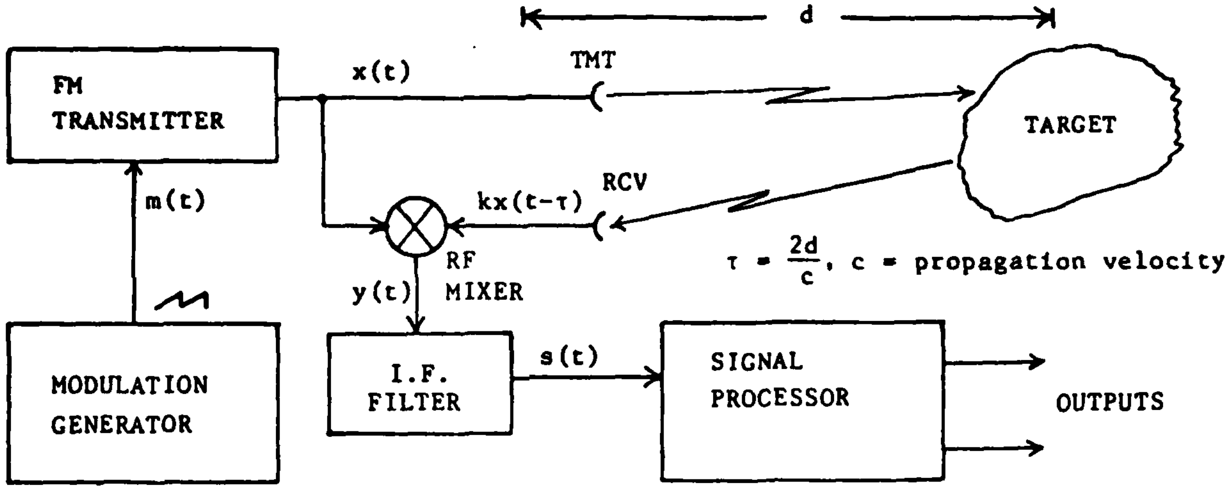

Figure 1. FM ranging system.

The IF signal $s(t)$ is processed in various systems to measure range and range rate as indicated by target delay $\tau = 2d/c$ and doppler frequency $f_d = 2V/\lambda$ (V = velocity and λ = wavelength). Signal processors may employ frequency discriminators, IF correlators, etc., to measure the appropriate parameters (see Selected Bibliography for details of various FM ranging systems). The purpose of the DIFSS is to generate an IF signal which can be used to test the ranging system signal processor.

3. IF SIGNAL DESCRIPTION

A frequency modulated signal can be described by

$$x(t) = \cos [\theta(t)],$$

$$\text{where } \theta(t) = \int_0^t \omega(x)dx. \tag{1}$$

$\omega(x)$ can then be expanded as

$$\omega(x) = \omega_m(x) + \omega_0, \tag{2}$$

where $\omega_m(x)$ is the radian frequency deviation due to modulation and ω_0 is the radian center frequency of the transmitter.

Correspondingly, the returned signal from a target delayed by time-delay

τ and attenuated by the factor k is given by

$$kx(t - \tau) = k \cos [\theta(t - \tau)]. \tag{3}$$

The mixer product is then

$$\begin{aligned} y(t) &= ck \cdot \cos [\theta(t)] \cos [\theta(t - \tau)] \\ &= \frac{ck}{2} \{\cos [\theta(t) - \theta(t - \tau)] + \cos [\theta(t) = \theta(t - \tau)]\}. \end{aligned} \tag{4}$$

c is the mixer gain coefficient.

Low-pass filtering removes the sum angle term occuring at double the RF carrier frequency to give a normalized IF signal described by

$$s(t) = \cos [\theta(t, \tau)] = \cos [\theta(t) - \theta(t - \tau)]. \tag{5}$$

Equation (5) can be expanded using (1) and (2) to give

$$\begin{aligned} s(t) &= \cos \left[\int_0^t \omega_m(x)dx + \int_0^t \omega_0 dx - \int_0^{t-\tau} \omega_m(x)dx - \int_0^{t-\tau} \omega_0 dx \right] \\ &= \cos \left[\int_0^t \omega_m(x)dx - \int_0^{t-\tau} \omega_m(x)dx + \omega_0\tau \right] \\ &= \cos [\theta_m(t) - \theta_m(t - \tau) + \theta_d]. \end{aligned} \tag{6}$$

The term $\omega_0\tau$ is the doppler angle θ_d. The mathematical model for the DIFSS is then given by (6).

For periodic modulations, $\theta_m(t)$ and $\theta_m(t - \tau)$ are periodic with period T. $\theta_m(t - \tau)$ is simply $\theta_m(t)$ displaced by time delay τ.

4. DIFSS OPERATING PRINCIPLES

The DIFSS computes the angle $\theta(t, \tau) = \theta_m(t) - \theta_m(t - \tau) + \theta_d$ and generates the function $\cos [\theta(t, \tau)]$ using a Programmed Read Only Memory (PROM) and digital-to-analog (D/A) converter (fig. 2).

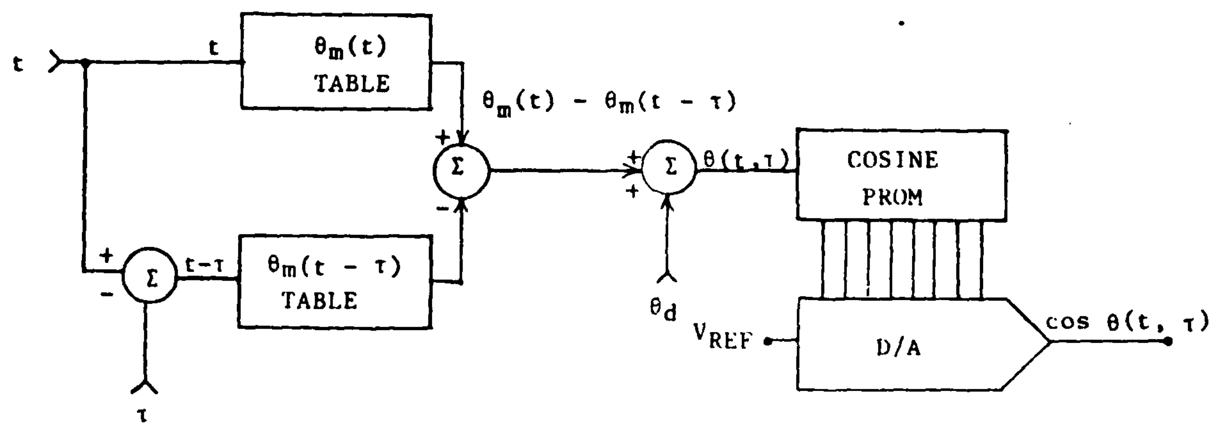

Figure 2. DIFSS functional model.

$\theta_m(t)$ is found by integrating the frequency modulation $\omega_m(x)$ over the interval T. N angular samples of $\theta_m(t)$ are converted to modulo 2π angles (θ_m') and the results expressed as binary numbers (θ_m''). Note that θ' refers to modulo 2π angles and θ'' refers to modulo 2π angles which are represented by digital numbers. The modulo 2π digitized angle samples comprising the angle tables are then stored in two identical Erasable PROM's (EPROM's). Simulation of a particular modulation waveform requires the programming and substitution of EPROM's corresponding to the modulation waveform.

Figure 3 illustrates the preceding discussion for a BT = 32 triangular modulation with a 2048 × 4-bit angle table.

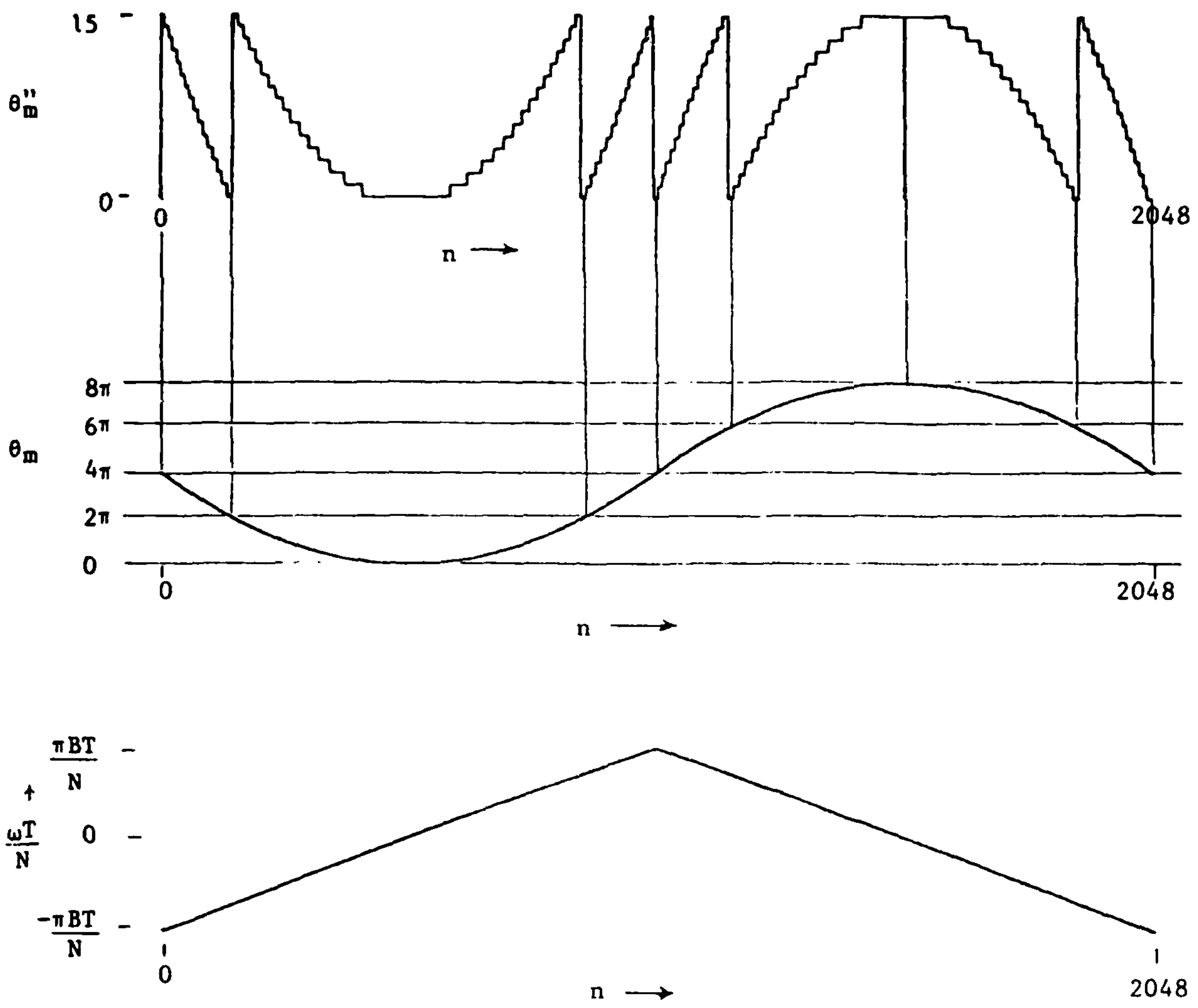

Figure 3. Modulation and angle functions for a BT = 32 triangle modulation using 2048 × 4-bit angle encoding (N = 2048).

$\theta''_m(t)$ is generated by accessing the table sequentially from beginning to end, then starting again, etc. $\theta''_m(t - \tau)$ is found by accessing values displaced in the table by an amount corresponding to time delay τ. The time delay Δt represented by one memory position is

$$\Delta t = \frac{T}{N}, \tag{7}$$

where T is the modulation period and N is the number of samples stored. Time

delay τ is then given by

$$\tau = m\Delta t, \tag{8}$$

where m is the displacement.

To generate $\theta''(t, \tau)$, $\theta''_m(t)$ and $\theta''_m(t - \tau)$ are accessed from the tables and the difference computed. Adding the doppler angle θ''_d completes the process for generating the IF signal angle $\theta''(t, \tau)$.

When the computation of $\theta''(t, \tau)$ exceeds 2π, the modulo 2π angle is generated. This is readily accomplished with digital hardware by using simple binary addition or subtraction and ignoring overflows. The computation of the difference angle $\theta''_m(t) - \theta''_m(t - \tau)$ is periodic in the time interval necessary to read the angle tables from beginning to end. The doppler angle is added independently and can be varied as needed for simulation.

The simulator is useful for studying system ambiguities or testing real-time hardware, provided certain constraints are observed. The prototype system was designed to provide 8 samples per unit $B\tau$ for a BT = 256 modulation (B is the RF bandwidth and T is the period). This means that the angle tables have a minimum of 8 samples per modulo 2π angular excursion. For studying ambiguities over the entire modulation period, all table values must be used. However, the period of the simulator is then necessarily N memory access times. When the table access speed is limited, the simulator period may be too long for testing real-time systems. This problem can be circumvented by "table skipping;" that is, by reading every other table entry or every fourth etc., the table can be spanned in less time. This procedure is restricted by the IF beat pattern sampling requirements. For example, if every 16th table value is read, only N/16 samples will be generated during the period T. If 8 samples per beat cycle are desired, the system tests are not valid beyond $B\tau$ = N/128. Simulation of τ values which are too high when table skipping will result in aliased IF signals and invalid results.

The prototype model of the DIFSS was designed to produce 8 samples per cycle for a BT = 256 modulation and used 2048 × 4-bit EPROM's for angle storage. For general use, a DIFSS should use N × 8-bit storage where N is chosen to give the desired number of samples for the largest BT to be simulated. Modulations with lower BT products can be accommodated by using the same length memory table (N) for all cases and choosing the table skipping increment to use only those values necessary. This approach gives considerable flexibility without hardware modifications. 8-bit angle encoding is recommended to achieve more accurate IF beat patterns.

5. DIFSS FUNCTIONAL BLOCK DIAGRAM

Figure 4 illustrates the functional components of the prototype DIFSS. A digital clock c_0 drives the n counter which addresses the $\theta''_m(t)$ EPROM. The n counter is implemented by adding a settable increment to the previous count to obtain the new value of n. This method is used because it lends

itself naturally to the table skipping feature. The m counter provides the address offset required to simulate a particular value of τ. This counter can be preset and advanced by the m controls in various ways to simulate dynamic target encounters. m is subtracted from n to give n-m which is the address for the $\theta_m''(t - \tau)$ EPROM. Two EPROM's provide simultaneous accessing of $\theta_m''(t)$ and $\theta_m''(t - \tau)$ to achieve maximum speed. The period of the simulator is determined by the time required to span the tables and can be expressed as

$$T_s = \frac{N\Delta T}{I} = \frac{2048\ \Delta t}{I}, \tag{9}$$

where Δt is the system clock period, I is the skip increment chosen, and N = 2048 for the present model.

The difference angle $\theta_m''(t) - \theta_m''(t - \tau)$ is computed in a 4-bit binary subtractor and the results set into a register. The doppler angle is obtained from a 4-bit binary counter driven by the doppler clock. Exclusive OR gates are used to control doppler direction by causing the doppler angle θ_d' to proceed from 0 to 2π (0-15 for θ_d'') or 2π to 0 (15-0 for θ_d'') in a sawtooth fashion. The IF phase angle $\theta''(t, \tau)$ addresses a 16 × 8-bit PROM programmed with a cosine function. The digital output representing cos $\theta''(t, \tau)$ drives a D/A converter to produce the IF signal.

The simulator is useful for studying ambiguous system responses for various time delays and doppler frequencies in a scaled-time mode or for testing hardware in a real-time mode. For studying ambiguities, an increment should be used which gives adequate samples for the highest frequency IF components. As noted previously, the period of the simulator may be longer than most real-time systems. Operation in this manner can then be considered a "scaled-time" mode. Doppler frequency and time delays can be set and controlled as desired for testing ambiguous system responses.

To test a real-time system, a common clock must drive both the simulator and the system being tested, and the table skipping increment must be chosen such that the simulator and system have the same period. In addition, the system under test must provide a short sync pulse to the simulator at the beginning of the modulation cycle. This sync pulse resets the n counter and thus synchronizes the simulator to the system.

6. DIFSS TEST RESULTS

Figures 5 through 13 illustrate the operating principles of the simulator and show typical measured results. The modulo 2π digitized samples stored in the θ_m'' EPROM are illustrated in figure 5 for both sawtooth and triangle FM. The function cos θ_m'' has also been displayed for reference. A D/A converter was used to plot the 4-bit angle samples.

Figure 6A illustrates a $B\tau = 8$ IF waveform for a BT = 256 sawtooth modulation with no doppler present. The flyback evident at the beginning also contains 8 beat cycles which are somewhat blurred. Figure 6B illustrates the

IF waveform for $B\tau = 1/2$. The blurred portion associated with each level illustrates that the difference angle computation does not give a constant result as the tables are spanned. This is due to the fact that the modulo 2π angle samples were encloded with only 4 bits. The simulator errors due to 4-bit encoding are reasonably compatible with the time quantization errors (8 samples per $B\tau$) which occur at the maximum IF frequency; however, a clearer IF signal can be obtained by encoding 8-bit angle samples rather than the 4-bit encoding used for this model of the DIFSS.

Figure 6C illustrates a $B\tau = 1/2$ IF waveform with a varying doppler angle. Figure 7 illustrates the same waveforms as figure 6 for triangular FM.

Figure 8 shows the amplitude spectra of IF signals for various values of $B\tau$ and sawtooth FM. The parameter fT corresponds to the modulation harmonic numbers. A small up doppler shift is present which causes the IF spectral lines to be shifted above the harmonic line positions. Figure 9 illustrates similar spectra for triangular FM. For this case, the doppler splits the IF on each side on the harmonic line positions in agreement with mathematical descriptions.

Figure 10 illustrates the use of the simulator in plotting the ambiguous range responses of a zero-order sawtooth FM system. A zero-order FM system is defined as one which measures the response which results from mixing the transmitted and received waves and low-pass filtering to obtain the doppler signal. The plots result from doppler shifting the IF signal by an amount corresponding to harmonic numbers (f_dT) and plotting the doppler response. This figure clearly illustrates the 8 samples per $B\tau$ resolution of the angle tables. Figure 11 shows similar ambiguous responses for triangular modulation.

Figure 12 illustrates the ambiguous responses for a sawtooth modulation for large doppler shifts to illustrate the ambiguity pattern. There are similar responses for each harmonic number which, if plotted, would give the total ambiguity function. Similar ambiguous responses for triangular modulation are shown in figure 13.

7. CONCLUSIONS

A digital IF signal for testing periodically modulated FM ranging systems has been developed and tested. The DIFSS is useful for testing real-time hardware and ambiguous ranging system responses in a scaled-time mode. The DIFSS can be implemented with readily available digital hardware and provides a reliable and controllable test device for the development of FM ranging systems.

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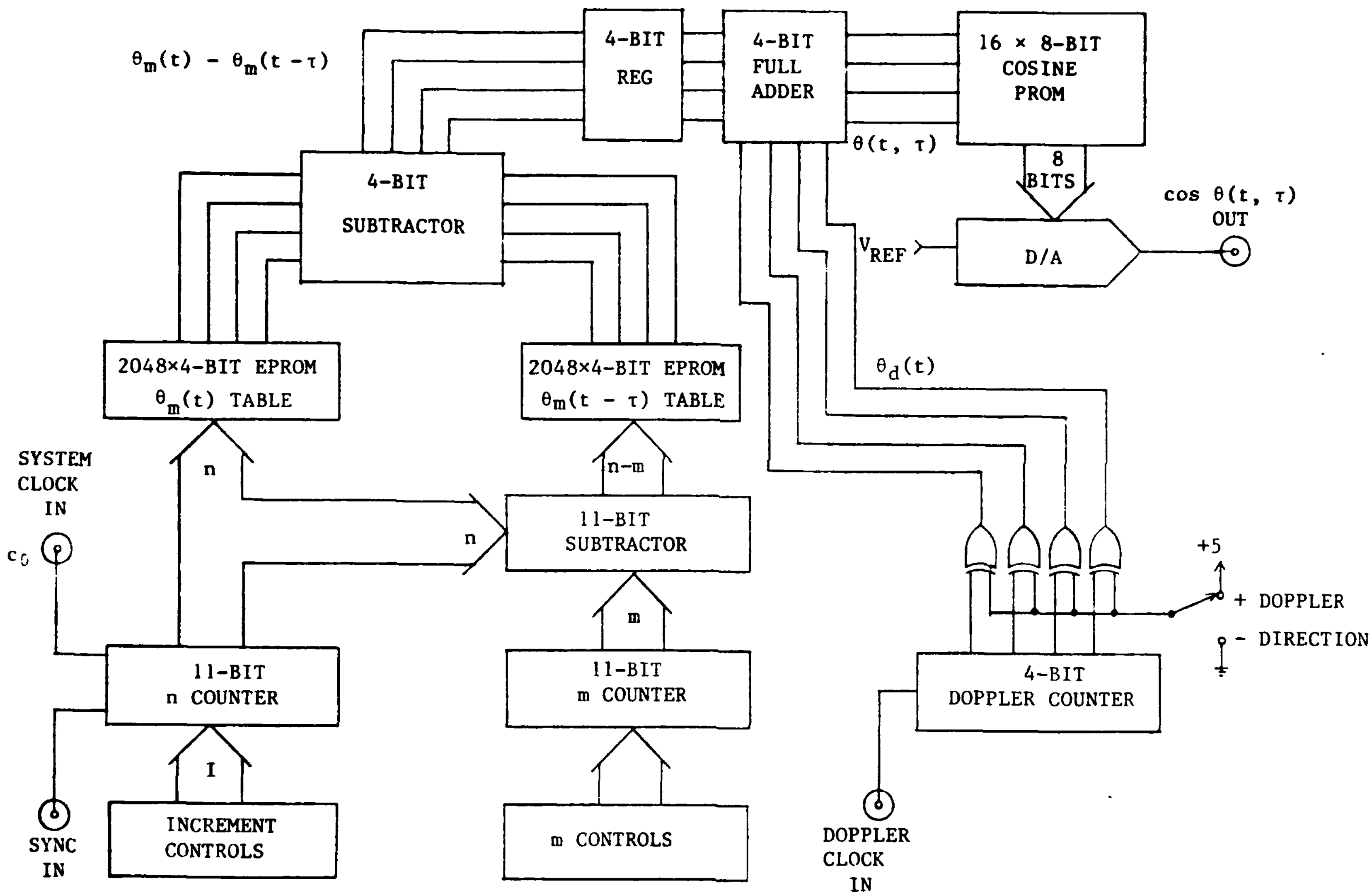


Figure 4. DIFSS functional block diagram.

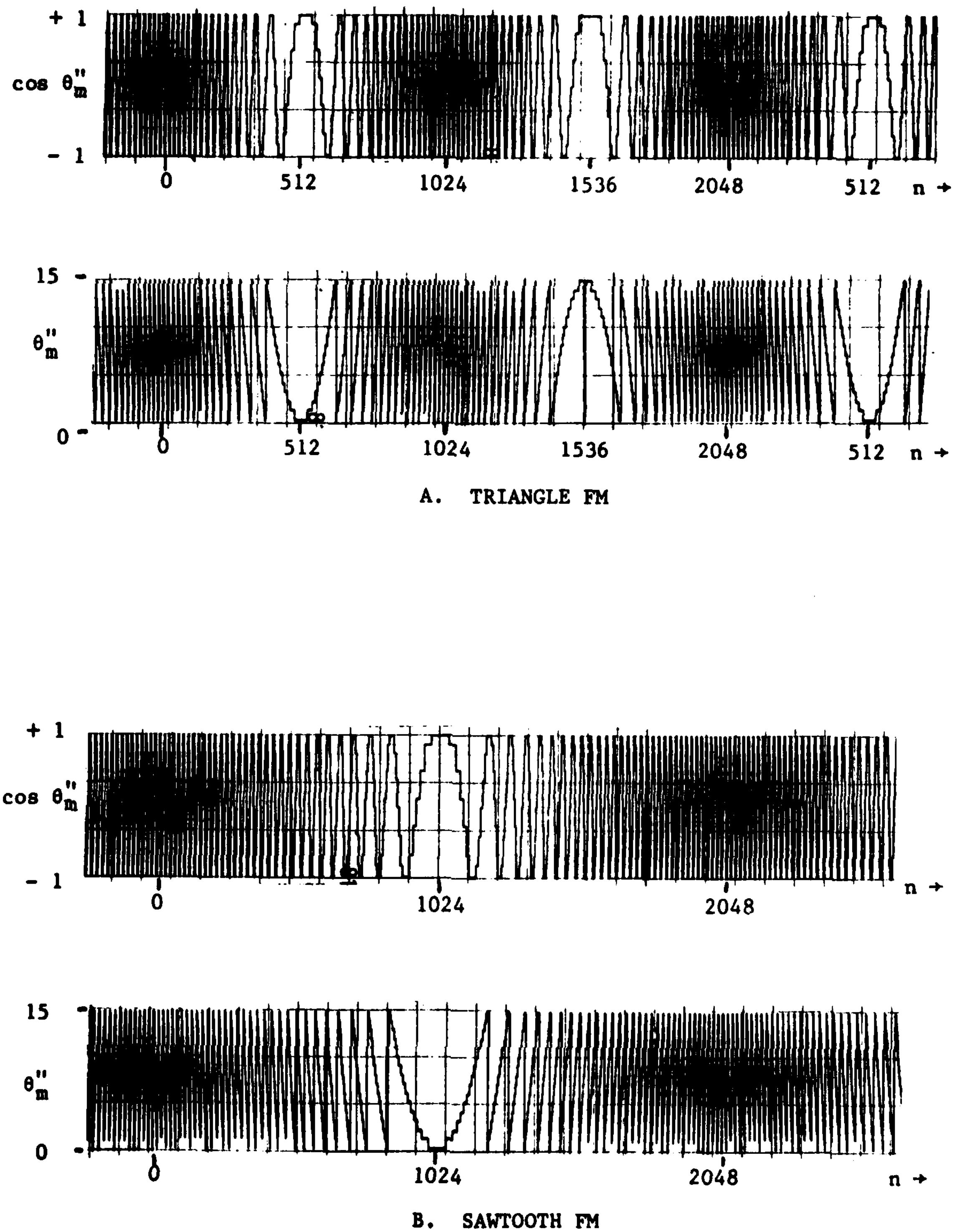
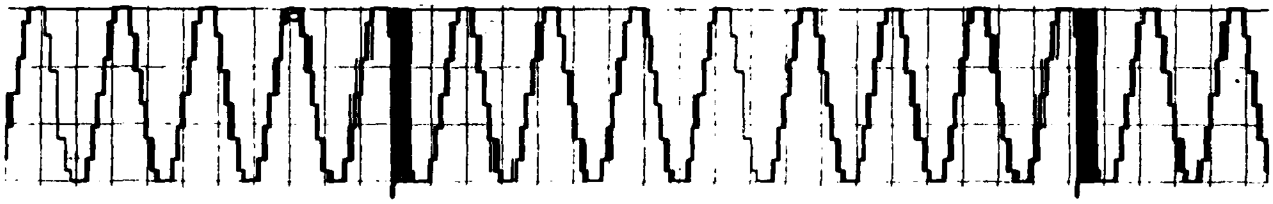
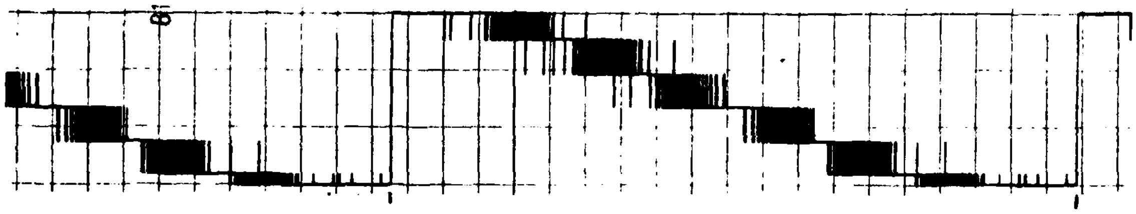


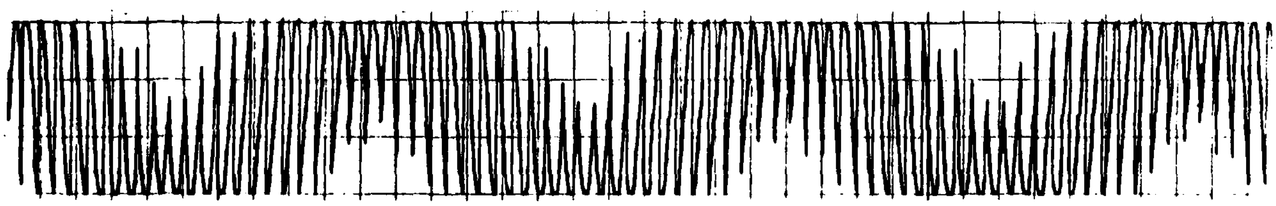
Figure 5. θ''_m angle tables and cos θ''_m for sawtooth and triangular FM (BT = 256).



A. $B\tau = 8$ IF WAVEFORM

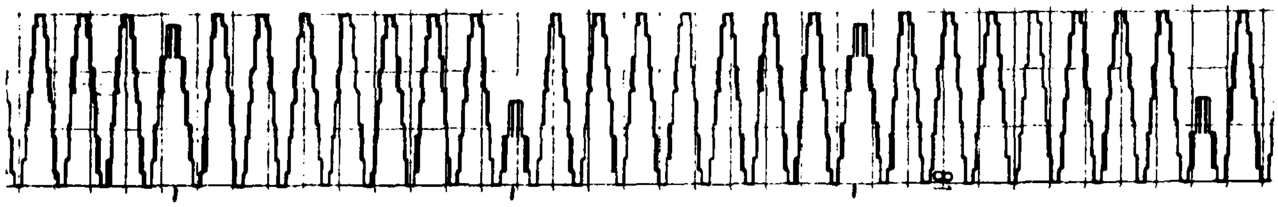


B. $B\tau = 1/2$ IF WAVEFORM



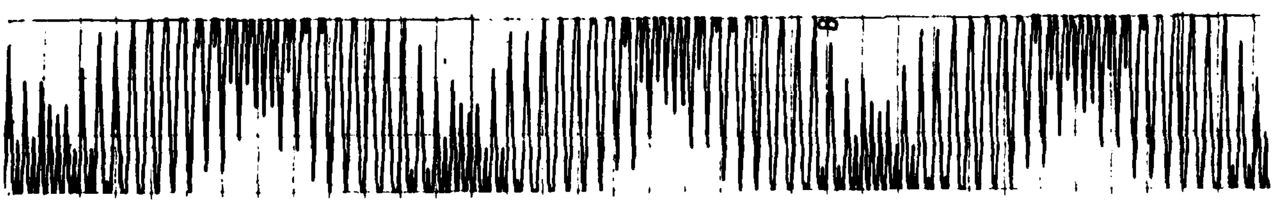
C. $B\tau = 1/2$ WAVEFORM WITH DOPPLER

Figure 6. Simulated IF signals for sawtooth FM.



A. Bτ = 8 IF WAVEFORM

B. Bτ = 1/2 IF WAVEFORM



C. Bτ = 1/2 WAVEFORM WITH DOPPLER

Figure 7. Simulated IF signals for triangular FM.

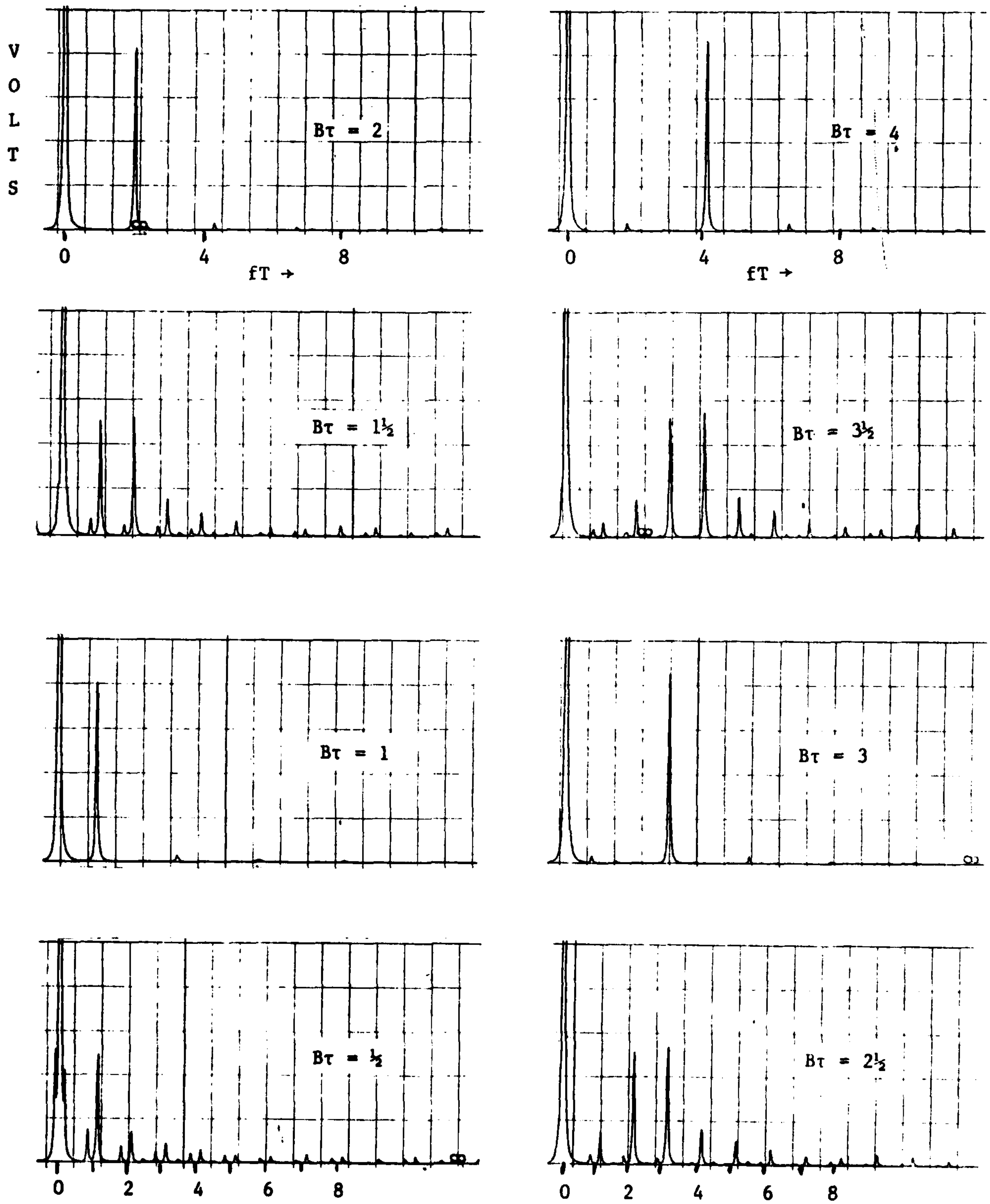


Figure 8. Spectrum of simulated IF signal with doppler shift for sawtooth FM.

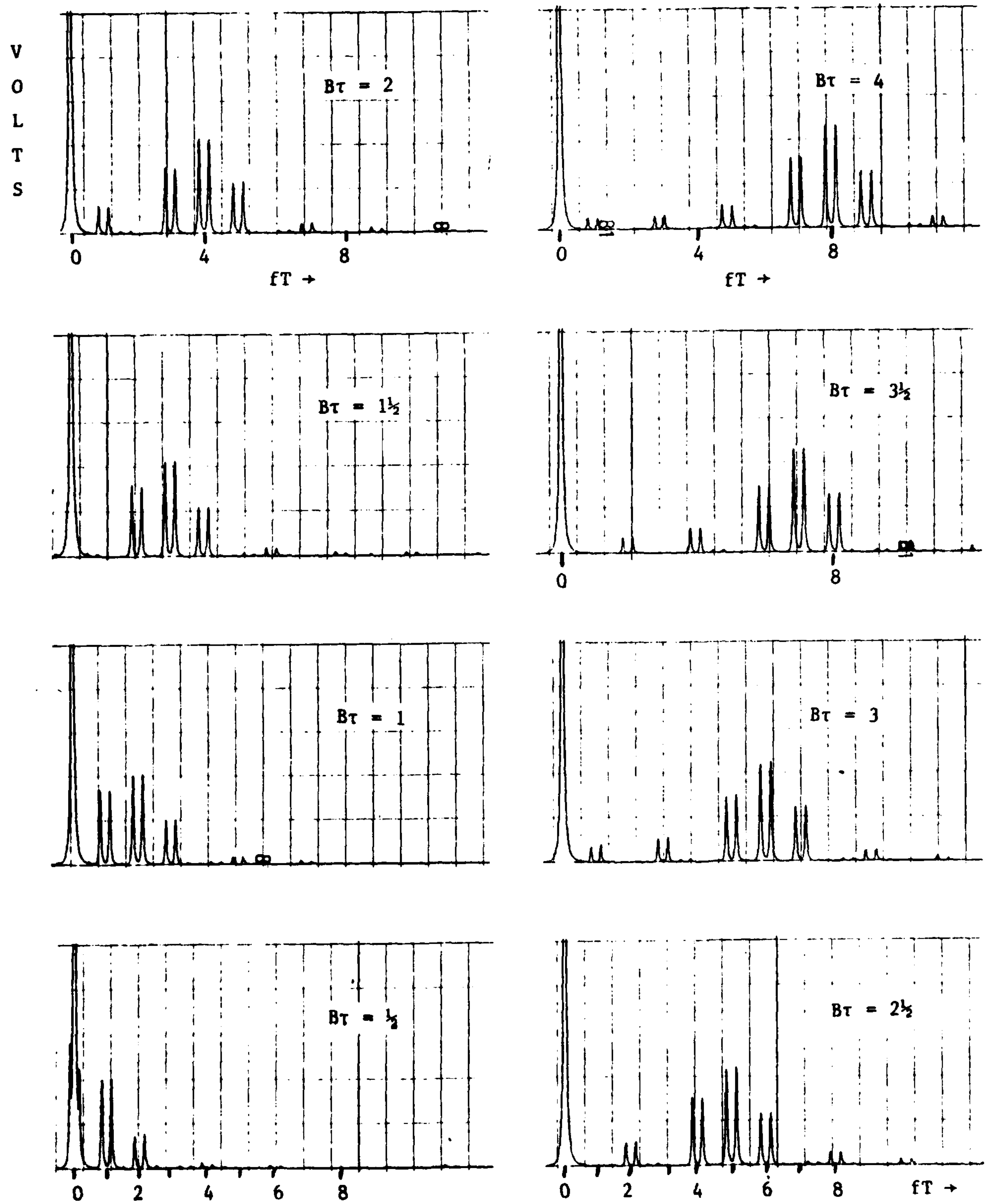


Figure 9. Spectrum of simulated IF signal with doppler shift for triangular FM.

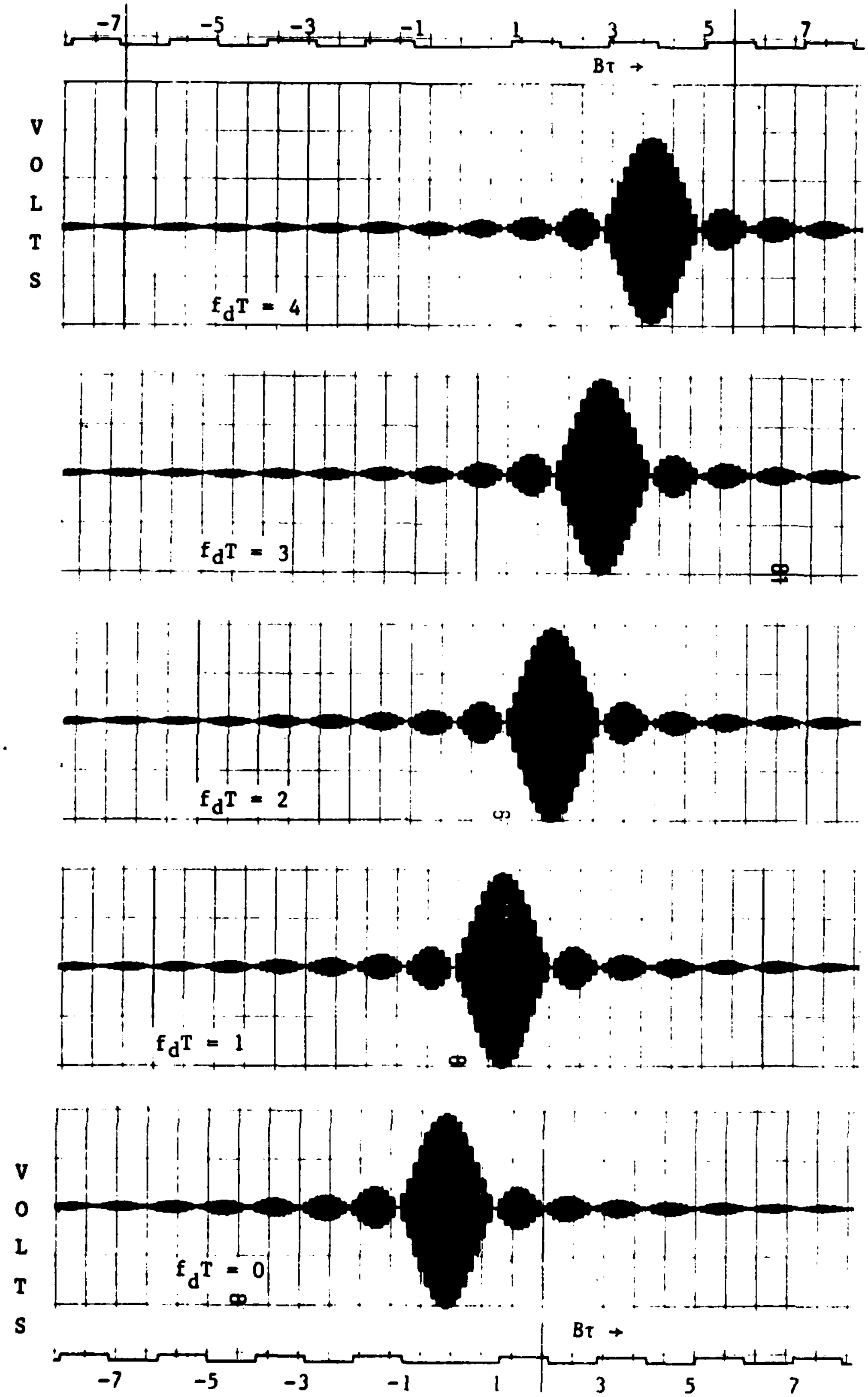


Figure 10. Response of zero-order FM system to simulated signals for sawtooth FM and large doppler shifts (f_dT = 0 to 4).

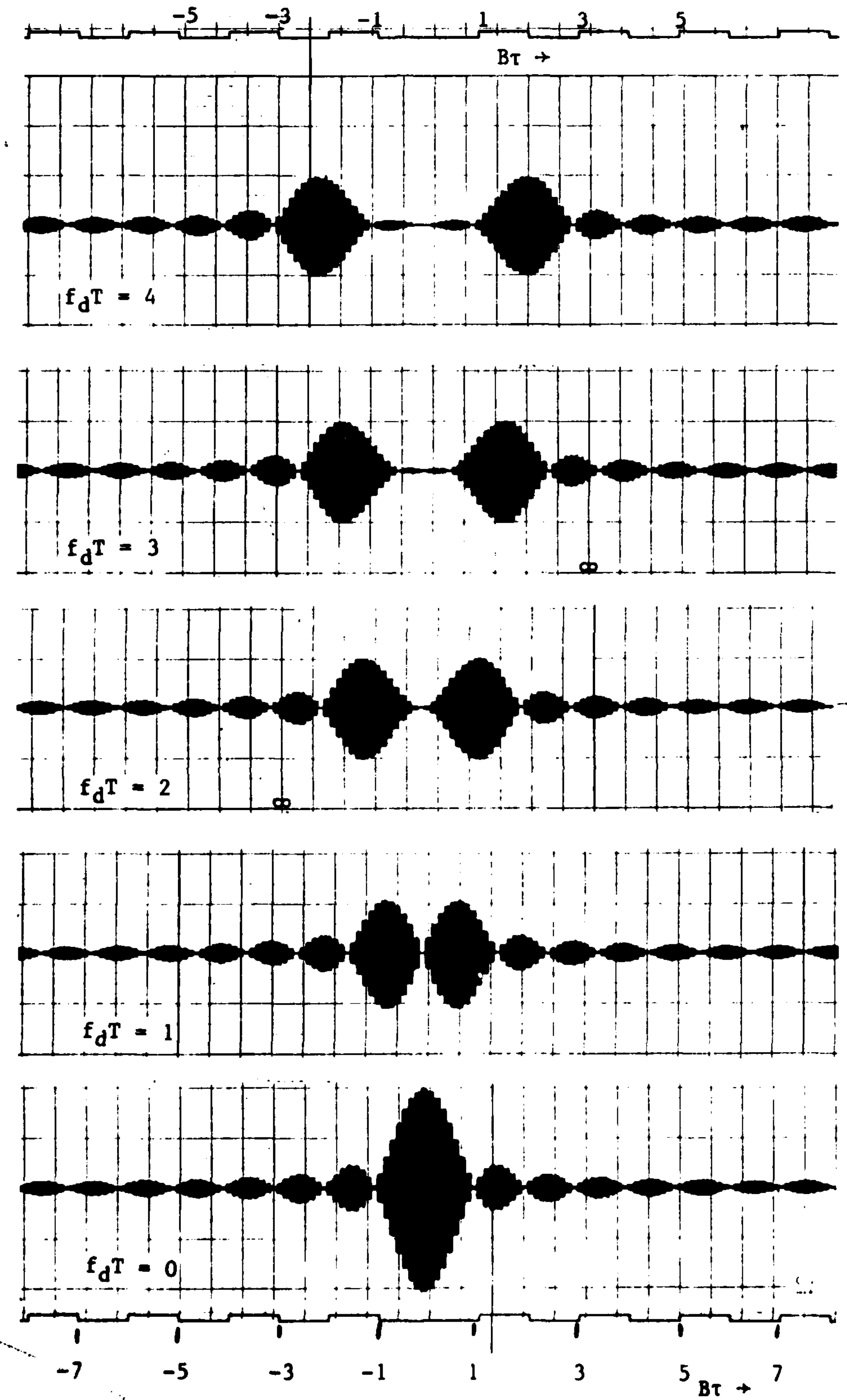


Figure 11. Response of zero-order FM system to simulated signals for triangular modulation and large doppler shifts ($f_dT = 0$ to 4).

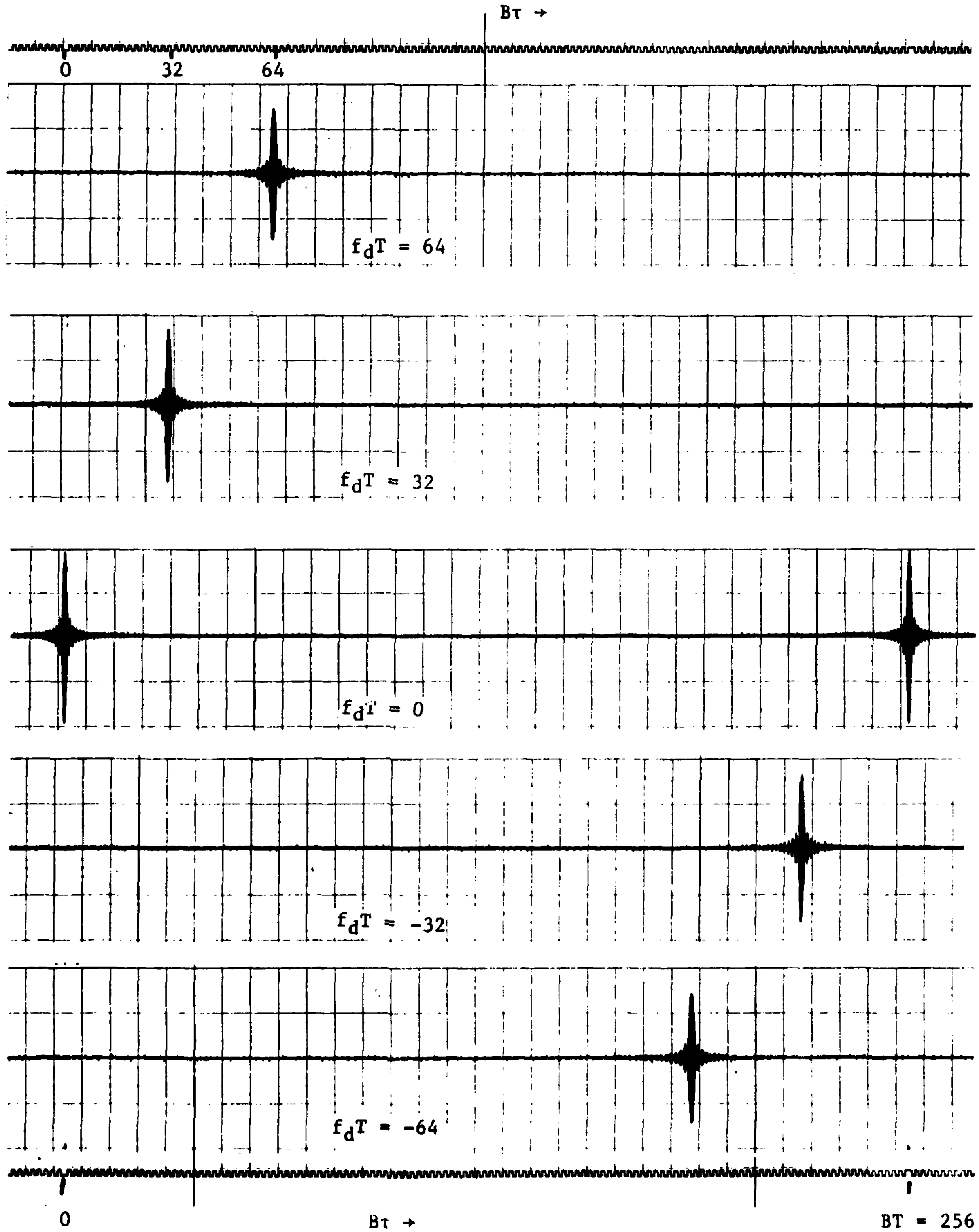


Figure 12. Ambiguities of a zero-order FM system for sawtooth modulation (BT = 256).

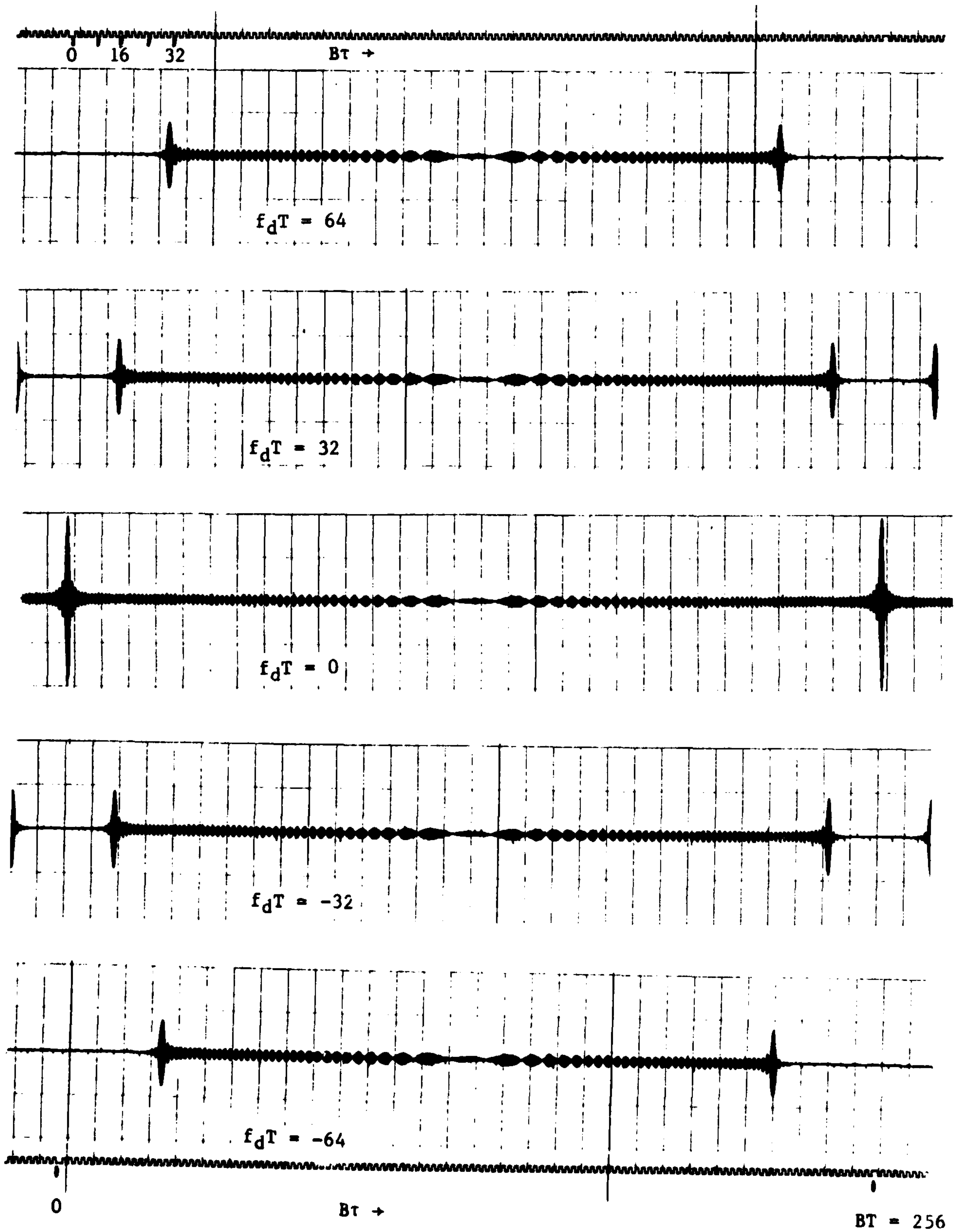


Figure 13. Ambiguities of a zero-order FM system for triangular modulation (BT = 256).

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